

## PRESENTACIÓN ORAL

### Observational challenges in dark energy models

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**Abstract.** Cosmological distances inferred from supernova Ia observations constitute the most direct and solid evidence for the recently detected accelerated expansion of the universe. In this contribution, we show some inconsistencies between two of the main light-curve fitters used for the elaboration of supernova Ia data sets, opening new observational challenges regarding the use of these luminosity distances when combined with CMB and BAO data. We also mention ongoing analysis related to alternative models. The resolution of these challenges will be crucial for XXI century cosmology.

**Resumen.** Las distancias cosmológicas inferidas a partir de observaciones de supernovas del tipo Ia constituyen la evidencia más directa y sólida de la recientemente detectada expansión acelerada del universo. En esta contribución, se muestran algunas inconsistencias entre las dos maneras más usadas para procesar las curvas de luz de las supernovas Ia, abriendo nuevos desafíos observacionales referidos al uso de estas distancias luminosas cuando son combinadas con datos del CMB y BAO. También se mencionan análisis en curso, relacionados con modelos alternativos. La resolución de estos desafíos será crucial para la cosmología del siglo XXI.

### 1. Introduction

The discovery of the accelerated expansion of the universe in 1998 through distant supernova Ia (SN Ia) observations was awarded with the Nobel Prize in Physics in 2011. Assuming that the universe, at large scale, is correctly described by an FRW cosmology, these observations of luminosity distances yielded the most conclusive evidence for the need of adding an extra component with negative pressure to the model, namely dark energy, responsible of the acceleration. The combination of these observations with, for instance, the cosmic microwave background (CMB) and the baryon acoustic oscillations (BAO) ones, support today the *concordance model* ( $\Lambda$ CDM) according to which 72% of the energy density of the universe is dark energy (Amanullah et al. 2010).

The flux measurements (or apparent magnitudes) in different epochs and distinct passbands are processed with the so called *light-curve fitters* to obtain luminosity distance values. The two most used methods are MLCS and SALT2 (e.g. Jha et al. 2007 and Guy et al. 2007). It is important to remark that a 0.2 apparent magnitude difference leads to a 10% error in the luminosity distance value. While MLCS only uses the nearby supernovae to calibrate its empirical

parameters, SALT2 uses the whole data set. But, when using the complete data set, SALT2 is forced to adopt a cosmological model for those supernovae that lie beyond the range where the linear approximation to the Hubble law is valid. Typically flat models are assumed ( $\Omega_k = 0$ ),  $\Lambda$ CDM or  $w$ CDM ( $w = \text{const}$ , being  $w$  the dark energy equation of state. The particular case of  $w = -1$  corresponds to a cosmological constant  $\Lambda$ ). Therefore, the distances inferred with SALT2 hold a degree of model dependence. Several authors have already pointed out that the obtained values for some cosmological parameters (for example  $w$ ) differ significantly depending on the fitter applied (e.g. Kessler et al. 2009, Sollerman et al. 2009 and Komatsu et al. 2011).

## 2. How flat is the universe?

In the framework of a  $\Lambda$ CDM model, allowing  $\Omega_k$  to vary, we studied the confidence intervals using the whole SNe Ia data set from SDSSII (Kessler et al. 2009) processed with MLCS and with SALT2. The analysis with MLCS (Fig.1, *Right*) showed that the flat case ( $\Omega_m = 0.27$ ) lies outside the  $3\sigma$  confidence level, while with the same data set, but processed with SALT2 this does not happen (Fig.1, *Left*).

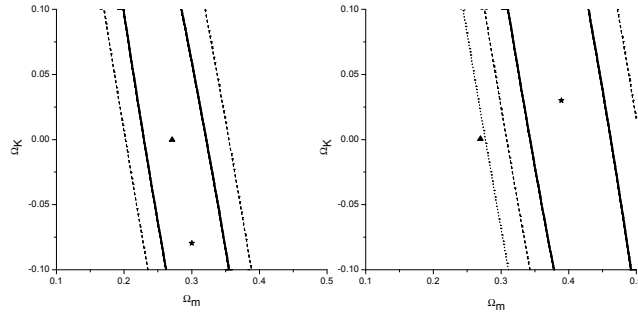


Figure 1. SDSSII SN Ia data set in the  $\Lambda$ CDM model framework. *Left*: Confidence intervals at 68.3% and 95% for SALT2. *Right*: Confidence intervals at 68.3%, 95% and 99.7% for MLCS. Best fits are indicated with a star whereas the standard flat  $\Lambda$ CDM ( $\Omega_m = 0.27$ ) is marked with a triangle.

Since the responsible of this fact is the fitter and not the SNe Ia, one could wonder which SNe Ia set to use to be combined with, for example, CMB data, which leave little margin to the variation of  $\Omega_k$  (e.g. Komatsu et al. 2009). Looking at Fig. 1, one would choose the data set processed with SALT2; however we ought to remember that SALT2 retains a degree of model dependence because typically a flat  $\Lambda$ CDM model is assumed. Some authors have remarked that imposing  $\Omega_k = 0$  could bring serious problems when reconstructing the equation of state  $w$  of the dark energy. Omitting only a 2% of curvature leads to the reconstruction, employing luminosity distances data, to yield very physically different results than when using  $H(z)$  values (Clarkson et al. 2007). This is the result of the well known  $\Omega_k - w$  degeneration (e.g. Spergel et al. 2007).

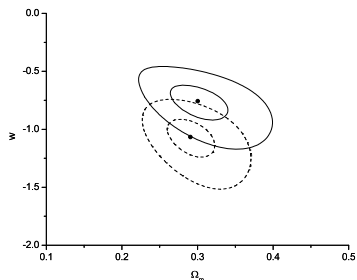


Figure 2. Confidence intervals at 68.3% and 99.7% coming from combining SN Ia and BAO/CMB data. Solid lines correspond to SDSSII (SALT2) whereas dash lines correspond to SDSSII (MLCS).

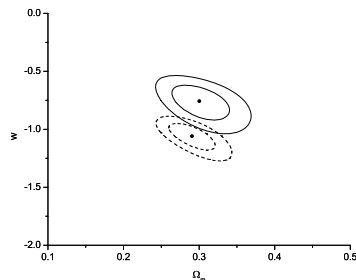


Figure 3. Confidence intervals at 68.3% and 95% from combining SNe Ia + BAO/CMB. Union2 (SALT2-dashed lines) vs SDSSII (MLCS-solid lines).

### 3. Tension between data sets or fitters?

In Wei (2010), a tension is found between SN Ia data sets, and also between the later with BAO and CMB. The tension was attributed to certain supernovae and the author proposed a truncation method to remove the outliers and release the tension. Guided by this finding, we found something similar between the Union2 (Amanullah et al. 2010) and SDSSII SN Ia data sets when combined with BAO/CMB data according to Sollerman et al. (2009). But the interesting thing was to find that this tension only appears when the data sets are processed with different fitters. Therefore, the tension is not between SN data sets but between the light-curve fitters used. We also found that using the same truncation method, the same SNe Ia data set behaves in different ways just for having been processed with one or another fitter, as if they were two different data sets (Bengochea 2011).

The comparison of the Figures 2 and 3 allows to appreciate how two light-curve fitters used for the same SN Ia data set produce the same result as two distinct SN Ia data set.

One of the main goals of the future observational projects will be to figure out if dark energy is a cosmological constant or something more exotic ( $w \neq -1$ ). In the search for such a characterization, *phantom* models ( $w < -1$ ) in which the energy density can become infinite at a finite time driving to a *big rip*, have not yet been observationally discarded (Caldwell 2002). Bearing this in mind, another interesting result was to find that, for several alternative theories, the fitters add an extra degeneration in the results, favoring for example that when combining SN Ia with BAO/CMB the equation of state  $w$  is phantom or not, depending on the fitter used (Table 2 of Bengochea 2011), or that certain parametrization for the dark energy predict a future deceleration or not (Li et al. 2010).

Some improvements to reduce this kind of systematic errors and others not mentioned here, have been developing (e.g. Sullivan et al. 2010 and 2011,

Marriner et al. 2011). Following what was showed by Sollerman et al. (2009), the study of how this kind of degeneration between light-curve fitters affects the result when SN Ia data sets are used to put observational constraints to inhomogeneous models is in progress (Bengochea 2012), being these later a very interesting subject to study, as an alternative to the FRW case, because of the capability of describing a vast variety of observations very well *without* dark energy.

#### 4. Conclusions

While assuming a FRW- $\Lambda$ CDM cosmology the evidence about the existence of dark energy seems undisputed, as of today the two most used light-curve fitters for the elaboration of the luminosity distance SN Ia data sets present inconsistencies between them, making the very same data set to behave, under certain circumstances, as two different ones, generating false tensions between SN Ia data, CMB and BAO. The extra degeneration produced in the analysis by these fitters make more difficult to characterize the equation of state  $w$  of dark energy. It is precise to elaborate calibration methods that are independent of the same cosmological models being evaluated or the prior  $\Omega_k = 0$ , get to better understand the evolution of the metallicity with the redshift, the variability of the intrinsic color and the dust extinction and other factors that allow to reduce systematic error sources. Some authors have already begun to work on this. On the other hand, the impact of the differences between the light-curve fitters must be also understood when SN Ia data sets are used to put constraints to free parameters of alternative models to the FRW case.

**Acknowledgments.** G.R.B. is supported by CONICET.

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